NASA-TM-107999

ON THE RATIONALE AND CONSTITUENCIES FOR A NASA PROGRAM OF SPACE APPLICATIONS RESEARCH AND DEVELOPMENT

7N-12-TM
124711

MAY 1987

(NASA-TM-107999) ON THE RATIONALE AND CONSTITUENCIES FOR A NASA PROGRAM OF SPACE APPLICATIONS RESEARCH AND DEVELOPMENT (NASA) 63 p

N93-70389 P. 63

Unclas

Z9/12 0124711

A REPORT OF THE
NASA ADVISORY COUNCIL

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: F

May 27, 1987

Honorable James C. Fletcher
Administrator
National Aeronautics and Space Administration
Washington, DC 20546

Dear Jim:

During his last year as Chairman of the Space Applications Advisory Committee of the Council, Art Mager undertook to complete and report on a study of the bases for NASA's Space Applications program and the constituencies served by that program. These efforts were in response to questions posed to the Committee by Burt Edelson, then Associate Administrator for Space Science and Applications, who was seeking a convincing rationale for extension of the important work NASA had done in the past primarily in communications and the many remote sensing applications programs. A draft of the report was reviewed and accepted by the Council last year. Because of its potential significance, it was agreed that the final report would be issued as a report of the Council.

I am happy to forward the final report to you with this letter. The report identifies strong reasons for NASA's conduct of Space Applications programs in communications, in remote sensing, and in microgravity, all associated with the need for advance of technology in these critical areas both for the benefit of our society and to contribute importantly to U.S. competitiveness. I trust that you and NASA management will be able to make good use of the identified rationales and constituencies in your development of important new programs in Space Applications. The Committee and especially Art have done a fine job in preparing this report.

Sincerely,

Dan

Daniel J. Fink, Chairman
NASA Advisory Council

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Reply to Attn of: EPS

May 11, 1987

Mr. Daniel J. Fink
Chairman, NASA Advisory Council
D. J. Fink Associates, Inc.
Key South Building, Suite 1120
1901 North Fort Myer Drive
Arlington, VA 22209

Dear Dan:

It is my pleasure to transmit, with this letter, the Space Applications Advisory Committee's report: "On the Rationale and Constituencies for a NASA Program of Space Applications Research and Development." The Committee is gratified that the Council has adopted the report and will publish it as a NASA Advisory Council (NAC) document.

As you recall, Art Mager was Chairman during the formulation of the study, which grew out of a series of questions posed to the Committee by Dr. Burton I. Edelson, Associate Administrator for the Office of Space Science and Applications. Art was so dedicated and committed to the effort that he agreed to oversee final preparation of the Report even after he rotated out of the Chairmanship of the Committee. I feel the Report is a fine product and that we all owe Art a debt of gratitude.

Sincerely,

Leonard Jaffe
Chairman, Space Applications Advisory Committee

ON THE RATIONALE AND CONSTITUENCIES FOR A NASA PROGRAM OF SPACE APPLICATIONS RESEARCH AND DEVELOPMENT

A NASA ADVISORY COUNCIL REPORT

PREPARED BY THE

SPACE APPLICATIONS ADVISORY COMMITTEE

MAY 1987

SPACE APPLICATIONS ADVISORY COMMITTEE

1983-86

Artur Mager, Chairman

Dudley G. McConnell, Executive Secretary

Communications Subcommittee
Leonard Jaffe, Chairman
R. W. Haight
Donald C. MacLellan
Harold E. McDonnell
Sidney Metzger
Lee M. Paschall
Wilbur Pritchard

Microgravity Subcommittee
Robert F. Sekerka, Chairman
Marvin A. Asnes
Grant Barlow
John R. Carruthers
Morris Cohen
Martin E. Glicksman
James A. Graham
David J. Larson, Jr.
Charles W. Mathews
Simon Ostrach
James T. Rose
William Sirignano

Remote Sensing Subcommittee
Lawrence R. Greenwood, Chairman
Pierre-Marie Adrien
Thomas F. Heinsheimer
H. R. Hopkins
David A. Landgrebe
Ernest L. La Porte
Maurice W. Long
Paul M. Maughan
John H. McElroy
Robert Ryan
William D. Siapno
David H. Staelin
Don Walsh
Wilford F. Weeks
Sylvan Wittwer

Information Systems Subcommittee
Gerald Estrin, Chairman
Ralph Bernstein
Jack Dangermond
Ida R. Hoos
George Ludwig
Douglas O. Reudink

TABLE OF CONTENTS

PREFACE

Even though very successful, NASA's program of research and development in space applications now requires a restatement of its rationale and an identification of its constituency.

As NASA and its predecessor National Advisory Committee for Aeronautics (NACA) have learned, the very success of their R&D programs often brings with it a questioning of the reasons that underlie the existence of these programs. Particularly during the budget and policy formulation processes, questions such as why NASA should do R&D that will benefit the satellite communications industry are often asked. Indeed, in the early 1970s, as a result of such a reevaluation of its effort, NASA withdrew its R&D in support of satellite communications, a move that later proved ill-conceived. This is not to say that a periodic external reexamination of the justifications underlying NASA's programs is wholly inappropriate, but only to explain why NASA's administration strives to ensure that such justifications remain unaltered by the changing circumstances.

Of course, NASA, like other government agencies, has a legislative charter and a number of legislative mandates, but these allow a variety of different interpretations. For this reason, what is needed goes beyond a legislative mandate, a justification that will clarify the boundaries of NASA's R&D effort in space applications and be acceptable to a broad spectrum of our citizens.

Public benefits make the most convincing argument in justifying the continued existence of federal programs. For space applications R&D, which often lacks immediately visible payoff, it is necessary to provide assurances that the applications will ultimately have great importance or wide national utility. To lend credence to such assurances and make the R&D truly useful, identification of those segments of our society that may have requirements for the applications that NASA is trying to evolve is needed. Early involvement of such constituencies in the formulation and conduct of R&D is essential. However, for some applications the constituency is not readily identifiable and remains to be developed. In such cases familiarization through early involvement of some potential users and possibly through changes in the direction of the proposed R&D (within bounds imposed by propriety and rationale) may be required.

This report by the Space Applications Advisory Committee (SAAC) attempts to formulate the rationale and provide some guidelines regarding the identification and development of appropriate constituencies. Although its preparation was requested by the Associate Administrator for the Office of Space Science and Applications, it is also intended for those who are involved in the yearly scrutiny of NASA's programs. The report was completed in 1986 and approved by the NASA Advisory Council (NAC) at its August 1986 meeting. It therefore reflects the status of project approvals and scheduling as of that date.

Artur Mager
Chairman
Space Applications Advisory Committee

EXECUTIVE SUMMARY

In this report the Space Applications Advisory Committee, at the request of the Associate Administrator for Space Science and Applications, reviews space communications, remote-sensing, and microgravity programs, paying special attention to their importance and need for NASA's R&D effort. Then, by considering the various legislative mandates, as well as who would benefit from the required R&D, how and why, SAAC formulates a rationale for NASA's effort in space applications R&D. In addition, suggestions aimed at the development of an appropriate constituency for space applications are made.

The results for each of the space applications areas are presented separately. Though they differ somewhat from each other, it is possible to summarize them by asking why and when space applications R&D should be supported by the government rather than by industrial profits, why such an effort should proceed in parallel with similar military R&D activities, and finally, why these R&D activities should be conducted by NASA rather than some other governmental agency.

There are six major reasons for government support of R&D in space applications:

1. To acquire fundamental scientific and technical knowledge that may prove useful in improving life and processes on Earth, such as that which we expect to gain from studies of Earth system science and microgravity phenomena.

2. To provide broad societal benefits, such as protection of life and property gained from weather forecasts and the operation of an international Search and Rescue Satellite system.

3. To furnish technical support for U.S. positions in international negotiations, for example, the allocation of the communications frequency spectrum and geosynchronous satellite locations.

4. To discover and characterize scientifically new phenomena (such as may occur when processing in a microgravity environment), which may lead eventually to enhanced operations in space as well as to novel utilization of space for the development of unique and valuable technological products that in turn create new space industries of benefit to our nation.

5. To maintain and ensure our position at the forefront of space applications, allowing U.S. industry to grow and utilize these new capabilities to the economic benefit of the nation. The high-cost, high-risk nature of work in space makes it too difficult for industry to fund R&D in space applications. Experience in satellite communications during the early 1970s demonstrates that R&D of space applications, when carried out by industry rather than by government, slows down (because of the high risk) into modest evolutionary advances from the prevalent state of the art and opens the way for foreign competition. To encourage U.S. industry to risk investment in new commercial space ventures the government needs to support space applications R&D in order to assure the industry that its space products or services will not rapidly become obsolete.

6. To enable U.S. space industries to complete effectively in world markets with similar industries in Europe and Japan, which receive direct and indirect subsidies from their governments. The seriousness and intensity of the foreign competition is currently exemplified by the French SPOT Earth remote-sensing satellite and the Franco-German and Japanese direct broadcast satellites. This competition must be addressed because the commercialization of space applications has the potential to contribute to the reduction of our foreign trade imbalance and therefore strengthen our national economy.

The rationale for NASA's R&D activities in space applications in parallel with similar military R&D activities is that civilian R&D is intended to lead to new commercial industries and products, which will have to compete in world markets and therefore will have to remain relatively unencumbered by military restrictions. Furthermore, military needs are generally quite different from civilian needs, putting great emphasis on survivability and ability to operate under adverse conditions, while the civilian requirements tend to emphasize the potential for profit.

The rationale for NASA's conducting space applications R&D, rather than some other governmental agency such as NOAA or the Department of Agriculture (which currently manage certain operational space systems), is based on the following reasons:

1. NASA has been formed and chartered for the specific purpose of being the U.S. civilian space R&D agency. Its responsibilities have been reaffirmed by recent legislative actions that mandate NASA to perform satellite communications and remote-sensing R&D.

2. The technology developed by NASA for scientific exploration of space is often directly adaptable to space applications, eliminating the need for new development or for technology transfer between agencies.

3. Only NASA has the facilities, the managerial and technical expertise, and the resources to conduct such a program. Transferring this capability to, or developing it in, other agencies would be grossly inefficient and would disrupt the ongoing work, possibly destroying a very valuable national asset.

The identification of constituencies with requirements for the space applications that NASA is trying to evolve is greatly influenced by the maturity of these applications. For some, such as space communications, readily identifiable constituencies already exist. For others, such as microgravity processing, the constituencies still remain to be developed. This development is necessary because such constituencies are needed to

(1) help set realistic sensor and data requirements;

(2) cooperate in the formulation and conduct of meaningful experiments; and

(3) aid the eventual commercialization of the evolved applications or their transfer to the appropriate government user agencies.

To this end the Committee recommends the following avenues for each of the space applications areas:

<u>Satellite communications</u>, being the most mature space application, already has a vocal and representative constituency. Nevertheless, current trends and

future prospects indicate that additional constituents are likely to be found within the information and data processing industries, which are growing very rapidly and are increasingly turning to private networks. Similarly, the development of mobile satellite communications will be of particular benefit to transportation companies (trucking, sea transport, railroads). NASA should approach these industries through their trade organizations and plan to develop cooperative demonstrations of mobile satellite communications. Other constituencies may be developed within (1) the Department of Commerce, which is concerned with the unfavorable balance of trade; (2) the Electronic Industries Association, which is seeking ways to overcome the loss of electronic manufacture to foreign competition; and (3) the regulatory and other government agencies, which depend on NASA for advice on communication satellite technology.

The constituency for remote-sensing applications reflects the benefits that they provide. Weather sensing, whose benefits are so obvious, has a representative user group, which forms a significant constituency. The important involvement of NOAA in the formulation of NASA's weather-sensing programs could be realized by restoring the previously existing, very effective cooperative NASA/NOAA agreement. Should the accuracy and details of long-term forecasts improve enough to make them really dependable and meaningful, additional users would be found within the many professional and trade groups whose plans critically depend on weather.

The land-sensing satellites, whose benefits at present are not as widely recognized, have an organized, vocal, supportive group whose interests are primarily focused on oil and mineral exploration. If and when the sensed data become available in a timely, dependable, ready to use form, other users may become a potential constituency for land satellites. These consist of various disparate groups, which could probably be approached through their trade and professional organizations or aggregated into a consortium similar to the Public Service Satellite Consortium (PSSC), which represents varied users of communication satellites.

Ocean and Earth system sensing are currently pointed towards provision of fundamental scientific and technical knowledge so that their present constituencies are likely to be found (outside of the Navy) within academic and scientific circles. It is important therefore that NASA reinstated a broader involvement of these communities not only in data analysis and interpretation, but also in instrumentation and the development of measurement concepts.

Eventually ocean sensing may be expected to provide information that should be of considerable value to various maritime industries. Therefore, NASA should try to develop user groups within those communities, which will not only help to establish realistic ocean sensing and data requirements, but also participate in the formulation and conduct of meaningful demonstrations.

The applications of microgravity processing are still very much in the discovery stage. At present, it is not clear from the commercial standpoint where the current, largely exploratory investigations will lead us. For this reason there is at present no strong commercial constituency in this area. However, the scientific and technological communities are receptive to the results obtained in this program, the quality of the work performed, and its relevance to other areas of science and technology. The development of a coherent constituency from among these communities will occur naturally, particularly among those directly involved, by supporting and encouraging publications in scientific and technical journals and by stimulating the formation of interested professional groups. There is also some early industrial interest in materials processing in space which, if commercially promising, could eventually lead to the formation of an important constituency. In the meantime, to maintain that interest, NASA should make every effort to facilitate microgravity experimentation and develop an adequate knowledge base that could help the industry assess the development risks.

1.0 INTRODUCTION

This report of the Space Applications Advisory Committee (SAAC) responds to two questions which the NASA Associate Administrator for Space Science and Application posed to the Committee:

1. What is the rationale for a NASA program of research and development (R&D) in satellite communications, microgravity processes, and remote sensing?

2. How should NASA develop a constituency for practical applications of space systems and technology?

Those questions were posed in the following context: In December 1981 as part of an agency reorganization, NASA formed the Office of Space Science and Applications (OSSA). This office was largely formed through a merger of the Office of Space Science (OSS) and the Office of Space and Terrestrial Applications (OSTA). However, the Technology Utilization function of OSTA has become a part of the Office of Commercial Programs and is not a part of OSSA.

At the same time, a change in Administration policy affected NASA activities. The new policy stated that the role of the Federal Government in R&D was to conduct long-term, high-risk research and that where near-term benefits were to be expected, the beneficiaries should fund the effort. Thus, funding for the AGRISTARS Program of remote-sensing research for agricultural applications was removed from the NASA budget. Up to that time, the policy had been that NASA would be the civil space R&D agency. NASA conducted research in cooperation with potential users and then transferred developed technologies (e.g., weather or communications satellites) to operational agencies or U.S. industry.

As a result of the new policy, NASA reoriented certain of its applications efforts toward more basic, less immediate research. For instance, NASA formulated an Earth science program around the concept of global habitability. Because of a previous policy change it had been well over a decade since the agency had initiated a communications satellite flight project.

It was in the context of these organizational, policy, and programmatic changes that the Associate Administrator posed the questions to the Space Applications Advisory Committee in order to initiate inquiry and discussion within the community and ultimately to gain its advice.

The Space Applications Advisory Committee is divided into four Subcommittees: Communications, Remote Sensing, Microgravity, and Information Systems. The chapters of this study were prepared separately by the first three of those Subcommittees and then summarized and integrated into one homogeneous report by the Chairman of SAAC. The Executive Secretary provided the introduction and the complete report was then reviewed by the full Committee to ensure consistency, completeness, and final concurrence. The Committee would like to thank Emily Lind Baker for her extensive help in editing the final report. Technical support was provided by Management and Technical Services Co.

2.0 SATELLITE COMMUNICATIONS RESEARCH AND DEVELOPMENT

2.1 Introduction

Communications are essential to business and national affairs. During the last 35 years the United States has secured its leadership of this technology by the development of extensive space communications. This accomplishment was stimulated and enhanced to a large extent by NASA's satellite communications R&D. However, as the benefits of this newly developed space application became evident, the rationale for additional government support of R&D in this area, even though legislatively mandated, became less clear. This report attempts to reestablish this rationale by examining the needs for continuing NASA's involvement in space communications R&D.

What are the needs for NASA's R&D role in satellite communications? First, there is a need to develop advanced technologies, which in the early stages are too costly and risky for the private sector alone. This need is driven to some extent by the fact that the governments of other countries have, as a policy, subsidized advanced technology development in communications. Second, there is a need to support U.S. positions in international negotiations. Lastly, there are some societal benefits that clearly should be provided by the Federal Government. The internationally operated Search and Rescue Satellite system, acclaimed for its assistance in locating distressed travelers, is supported as part of NASA's satellite communications technology program. These needs are discussed following a brief summary of the legislation that spells out NASA's responsibilities in support of satellite communications. The NASA program is then related to the above needs, followed finally by some suggestions of ways in which to build a broader constituency for the program.

2.2 The Legislated Mandate

NASA's role in satellite communications is specified in the National Aeronautics and Space Act of 1958, as amended; in the Communications Satellite Act of 1962; and in the Legislative History of the FY 1985 NASA Authorization Act (Public Law 98-361).

The National Aeronautics and Space Act of 1958, as amended, contains the broad declarations of NASA's role in space activities. In it Congress states that NASA shall be responsible for conducting the aeronautical and space activities of the United States "to contribute materially" to one or more of the following objectives [from Section 102(c)]:

(1) The expansion of known knowledge of the Earth and of phenomena in the atmosphere and space;

(2) The improvement of space vehicles;

(3) The development of operation of such vehicles;

(4) Long-range studies of potential benefits from the utilization of space activities, and studies of the problems involved therein;

(5) The preservation of the role of the United States as a leader in space science and technology and in the application thereof.

In a later amendment to the Act (1), Congress declared that the general welfare of the United States requires that NASA (as established by Title II of this Act) seek and encourage to the maximum extent possible, the fullest commercial use of space.

NASA's role in satellite communications is further specified in the Communications Satellite Act of 1962. This act contains the responsibilities of COMSAT, the Federal Communications Commission (FCC), and NASA. It requires that NASA

(1) Advise the FCC on technical characteristics of the communications satellite system;

(2) Cooperate with COMSAT in research and development to the extent seemed appropriate by the Administration in the public interest;

(3) Consult with COMSAT with respect to the technical characteristics of the communications satellite system. Implicit in this assignment of responsibilities is the requirement that NASA maintain a significant R&D effort in satellite communications to ensure that its advice, cooperation, and consultation are meaningful.

A much more specific statement of the Congressional view of NASA responsibilities is contained in the FY 1985 National Aeronautics and Space Administration Authorization Act (Public Law 98-361), Senate Committee Report Section, Report No. 98-455. This report states that

(1) "The communications research analysis program provides the high-risk technology required to ensure continued U.S. preeminence in the field of satellite communications" (page 34). This is a clear reaffirmation, specifically applied to communications satellites, of the general guidelines for NASA to preserve the role of the United States as a leader in space technology application [Section 102(c)(5)]. Congress also states that the work should include the ground segment of the system.

(2) NASA's "technical consultation and support program will continue to provide for studies of radio interference, propagation, and special systems required for the growth of existing satellite and the extension of new satellite applications" (page 35).

(3) NASA shall "assist other Federal agencies and public sector organizations in the development of experimental satellite communications for emergency, disaster, and public service applications" (page 35).

and lists:

(4) The major elements of the Advanced Communications Technology Satellite program (ACTS). Under a section entitled "Committee Comments" the Committee discusses the large future market expected for satellite communications, the dominance of the United States in this field at the present time, the "noticeable inroads" of the Japanese and European space programs, due not only to their increased commitments, but also to the lack of NASA R&D in the 1970s. Based on this, they not only support R&D for the ACTS program, but also recommend that it include flight tests to provide operators and owners of future systems with the confidence needed to implement these new technologies (pages 36 and 37).

Finally, the report reexamines

(5) NASA's role in communications satellite R&D and concludes that "NASA has a fundamental role in communications satellite technology development" (page 37).

2.3 The Need to Provide Expertise for International Negotiations

The radio frequency (RF) spectrum is extremely valuable and limited. Until the advent of man-made satellites, international negotiations were largely concerned with those frequencies useful for broadcasting or long-distance (international) communications, that is, the lower end of the spectrum. With the advent of satellites, the allocation of the entire radio frequency portion of the spectrum became a contentious international issue. In addition, since the communications satellites are generally placed in geosynchronous orbit over specific areas, there has been an increasing pressure to assign these slots to nations in specific areas. Such internationally legislated allocations could preempt desired utilizations or forestall continued growth of U.S. interests.

Traditionally, international negotiations at the World Administrative Radio Conferences and in the International Consultative Committee on Radio have been based on the technical factors surrounding an issue. Thus, to properly guard our national interests the United States must remain in the technical forefront of all applications involving the radio frequency spectrum and the use of geostationary and other suitable orbits.

To ensure that this will be so, NASA has been given the responsibility to provide the Department of State, Department of Commerce, FCC, and COMSAT (2) with expert information from which national positions could be established and subsequently supported in international negotiations. But while, at present, NASA has the required expertise, to maintain this capability it needs to continue its R&D in satellite communications.

2.4 The Need for Advanced Technology Development

In the late 1950s, in response to its Charter, NASA began a program of space communications technology that eventually gave rise to the current worldwide capability for commercial space communications. Within 15 years of the inception of this technology program, American industry had obtained such a dominant position in the embryonic field of satellite communications that further federal funding for technology development was deemed unnecessary. NASA's support was subsequently withdrawn as a matter of national policy. Implicit in the withdrawal of NASA support was the expectation that further technical progress was to be accomplished by U.S. industrial suppliers of communications spacecraft and by their customers.

This commercially supported R&D effort did produce some evolutionary technical advances: low-gain Earth-coverage antenna beams were supplanted by high-gain moveable spot beams and by limited beam configurations; large spacecraft with dozens of transponders replaced the early primitive INTELSAT satellites; congested operation at C-band was relieved by development of dual polarized antennas and by operations at K_u-band; and the simple "bentpipe" mode of operation was augmented by satellite channel switching for variable routing of high-rate communications.

These evolutionary advances, however, have not kept up with the technological developments that were then taking place under the auspices of the Department of Defense or in other countries. One might expect that the results of the military R&D effort could be adapted to civilian uses. Unfortunately, this cannot be done because civilian R&D is intended to lead to new commercial products, which eventually will have to compete in world markets and therefore must remain free from military classifications, and because military R&D is mainly directed toward a class of service that is markedly different from that required by commercial users. Military systems emphasize low-rate, jam-proof, survivable communication to small, "disadvantaged" ground terminals. Commercial systems provide high-rate, jam-vulnerable, switched service between large, powerful ground terminals in a manner that can effectively compete with ground systems.

The lack of substantial advances in the state of the art during the time that NASA withdrew its support of satellite communications R&D also spurred the development of foreign competition. France, Germany, England, Italy, and Japan had all, at the national level, recognized the fundamental political and economic importance of satellite communications and had decided to provide governmental support to their domestic suppliers. NASA's withdrawal provided added impetus to this decision and the foreign programs began to take shape very rapidly. Japan launched the first of its ETS series in 1975 as part of a coherent space technology plan that encompassed satellites, launch vehicles, ground terminals, modulation equipment, and the financial support to establish an export industry. The French/German Symphonies were launched in 1974 and 1975, establishing European credibility in satellite bus design and satellite communications hardware. Italy followed with its SIRIO in 1977. England began developing its capabilities in late 1969 with the first of its Skynet series of military spacecraft and continued with the OTS spacecraft in 1977. All these countries took advantage of the hiatus in NASA's technology support, and are now challenging the American communications satellite industry. Moreover, all have specific programs that continue to do so, such as Japan's CS and BS series, the European L-SAT, MARECS, the French Telecon, Italy's ITALSAT, and the French, German, and Scandinavian high-powered direct broadcast satellites. Consequently, they pose serious threats to American dominance in a field the United States pioneered.

As the above discussion makes clear, the withdrawal of NASA's support during the early 1970s demonstrated that R&D of satellite communications when carried out by industry, rather than by government, led to relatively modest, risk-free, technological advances, which were not sufficient to maintain commercially competitive positions in world markets.

Conscious of this situation, NASA resumed its support for space communications technology in 1978, initially by funding studies to define the next generation of communications satellite services. The current NASA communications program is the outgrowth of these studies, which identified the high-risk technologies that must be developed before new satellite service can be achieved. The required advances in technology are a quantum leap in sophistication and risk compared to anything being planned by industrial suppliers today. The objective of the NASA program is to develop and demonstrate these requisite high-risk technologies. The cost associated with this risk is high enough to preclude any attempt by a commercial company or consortium to undertake the development of the next generation of technology.

The technology plans in other countries continue to be aggressive. The ACTS program will help to reestablish the U.S. preeminence in space communications.

2.5 NASA's Communications Technology Plan

To appreciate the significance of the NASA communications program, we should consider the service now available via satellites. Current communications satellite systems are an alternate means of providing a long-familiar service, the relay of high-capacity, point-to-point trunk communications, which was historically accomplished through terrestrial facilities. The distance-insensitive economics of satellite relay offered a less expensive alternative over long distances. Just as satellite relay with its particular economies supplanted long-distance ground relay, we can foresee the day when light-fiber relay with its economy of large available bandwidths will supplant some point-to-point satellite relay services. The significance of NASA's reconstituted space communications program lies in the fact that it will provide the technology base for entirely new forms of communications services that can become available only through the medium of communications satellite relay.

In the first of these, the satellite will serve as a switching and routing center to control the flow of information at the level of an individual voice circuit. It will functionally replace the electronic switching system found in the local exchange, and in this sense, the individual subscriber line will extend all the way into the satellite, which will be able to provide it with worldwide connectivity via crosslinks. In its ACTS program, NASA is pursuing the technology for this service.. For this program it is necessary to develop both terminal and satellite technology together, since in this type of service they are closely coupled technically and operationally (3). In fact, because the satellite performs a complete demodulation/remodulation of the received signals, it is impossible to test either satellite or terminal without the other. For the satellite, principal technical areas that require development include narrow, rapidly scanned, multibeamed antenna systems, which will provide large-system capacity, efficient use of the spectrum by frequency re-use, and rapid access to any point in the field of view. Also included are very high speed baseband processors to demodulate, switch, route, and remodulate the very wide bandwidths necessary to accommodate the heavy traffic; high-efficiency, high-power K_a-band RF amplifiers; and efficient low-noise receivers. In addition to these, there is a whole set of technologies that must be addressed relative to precision stabilization of large antennas and pointing of narrow-beam antennas.

The pursuit of these technologies must eventually proceed beyond the immediate technical goals of the ACTS program, since expanded commercial versions of ACTS with more and narrower beams for increased circuit capacity can be expected in the future. In the ground terminals, the technology for high-speed time-division multiple-access switching must be developed, as well as the technology for control of the entire system operation.

In a second new class of service, satellites will provide connectivity for voice circuits from small, mobile platforms, private passenger vehicles, trucks, ships, and public vehicles of all sorts. Limited bandwith for this service was allocated in the 800 MHz band at the 1979 World Administrative Radio Conference (WARC); FCC approval is expected in the near future. In this service, the overriding system requirement is to make the myriad of small terminals cheap enough to be affordable. This can only be done by placing the burden for closing the communications link most heavily on the spacecraft. At 800 MHz, the satellite must have a very large antenna aperture that supports a multiplicity of narrow beams. This is necessary to close the RF link and to allow multiple re-use of the limited available bandwidth. Antenna sizes will grow beyond 50 meters for a fully operational system that can support several dozen beams simultaneously. The technology for realizing this is in its infancy, but plausible approaches have been identified.

In anticipation of the demand for affordable low-cost terminals, NASA must continue its exploratory development work to increase the available technology base. Since the technology of ground terminals is the key to the affordability of space communications systems, NASA must address the development challenges that will enable industry to achieve small affordable terminals with particular emphasis on producibility in large numbers.

While the United States is debating these questions, the Japanese are well aware of the significance of low-cost terminals. At the 1984 International Astronautical Federation they described their feasibility study that will lead to the launch of an experimental satellite about 1990 with equipment in the 40/50 GHz bands. It is aimed at developing a system for use with small, inexpensive Earth stations (1-foot diameter antennas) and has the potential of placing Japan in a position to capture the low-cost terminal market.

Underlying the pursuit of technical elements for these new services is the continuing need for system definition studies and market assessment studies to provide guidance to the technology development efforts. No one can foresee exactly how these new services will develop, and it is necessary to re-assess at regular intervals where the correct technical path may lie. We can be sure only that services of this kind will come about, whether through the agency of American technical enterprise or that of some other country.

2.6 Rationale for NASA's R&D

It is apparent from the above discussion that there is a manifold rationale for NASA's conduct of R&D in satellite communications. The societal benefits derivable from the Search and Rescue Satellite system and the need to maintain technical expertise for support of U.S. positions in international negotiations clearly justify NASA's support of these activities as a purely governmental responsibility. But the legislative mandate goes further than that: it delegates to NASA the provision of "the high-risk technology required to ensure continued U.S. preeminence in the field of satellite communications." As the experience of the early 1970s demonstrated, maintaining that preeminence in space communications R&D cannot be left to industry and is not directly derivable from similar R&D conducted by the military. The high-cost, high-risk nature of R&D in space prevents the industry from producing appreciable advances in the prevalent state of the art, and the lack of such advances stimulates foreign, government-subsidized competition. Furthermore the military R&D in satellite communications is not immediately translatable to civilian uses because it is encumbered by classification restrictions and because it tends to emphasize services that are markedly different from those required by the commercial sector.

2.7 Constituency Development

Satellite communications, being the most mature space application, already has a representative constituency. Nevertheless, when considering the question of whether users who may have requirements for satellite communications could be identified, the Communications Subcommittee first established a list of many of the potential elements of such constituencies (Table 1). NASA should consider developing user groups in all of these communities because such constituencies are needed to help define meaningful experiments and to aid the eventual transfer to commercial and/or governmental utilization of the applications. The following are several specific suggestions to illustrate actions that should be taken for each of the categories in Table 1.

2.7.1 Information Industry

Large private concerns, principally those dealing with information processing and movement, are increasingly turning to private networks and to the strategic advantage those networks often provide. Many of these networks are based upon satellite technology. The banking community, for example, proposes to utilize the next generation of automatic teller machines in order to offer a wider range of services to the public without requiring fully staffed branch offices. Communications costs currently limit their ability to

TABLE 1

ELEMENTS FOR A COMMUNICATIONS CONSTITUENCY

USERS
- Government
  - Bureau of Land Management
  - Department of State
  - Department of the Treasury
  - Drug Enforcement Administration
  - Federal Aviation Administration
  - Federal Bureau of Investigation
  - National Park Service
  - Voice of America
- Industrial
  - Information Services
  - Information Processors
    - Banks
    - Insurance
  - Industrial Associations
    - American Trucking Association
    - International Communications Association
    - Tele-Communications Association

SUPPLIERS
- Spacecraft
- Launch Vehicle
- Earth Station
- Components

REGULATORY
- Department of Commerce
- Department of Defense
- Department of State
- Environmental Protection Agency
- Federal Communications Commission

ACADEMIC
- Communications
- Engineering
- Science

PUBLIC
- Public Good Users (Public Service Satellite Consortium)
- Search and Rescue

implement this concept. Satellite technology in its broadcast mode (point-to-multipoint) offers a solution if very low-cost, two-way Earth stations were generally available.

The data processing industry represents a potential constituency for the NASA communications research activity. Information processing capabilities are growing by an order of magnitude every 6 years. The increase in such capabilities will make demands upon communications in ways not yet understood. These organizations should be encouraged to make inputs into the NASA program to ensure that technology is available to meet their projected needs and to facilitate the eventual commercialization of that technology.

These groups can be approached by direct inputs to the major companies or through industry associations or industry communications user group associations, such as the International Communications Association (ICA) and the Tele-Communications Association (TCA).

2.7.2 Industrial Private Networks - Mobile Service

The development of mobile satellite communications technology will be of particular benefit to transportation companies (trucking, sea transport, railroads). NASA should approach the corresponding trade organizations (American Trucking Association, American Institute of Merchant Shipping) to determine how this service could address problems in transportation. NASA should then develop cooperative demonstrations that would convincingly demonstrate the ultimate commercial value of this program.

2.7.3 Government Agencies

Regulatory and other agencies, such as the Federal Communications Commission or the Department of State, look to NASA for competent technical advice on communications satellite issues. NASA cannot provide this support if it does not remain technically current through an active research program in communications satellite technology. Accordingly, NASA should try to develop a constituency within these agencies, which would help to define national interests in terms of the importance of continued communications R&D to the preservation of our options regarding the use of the RF spectrum.

2.7.4 Electronic Industries Association

Traveling Wave Tube Amplifier (TWTA) technology is being pursued by French, German, and Japanese corporations. All the development has been initially funded by their respective governments. These foreign corporations, seeded in their R&D by their governments, are now in a strong and successful selling position in the competitive world market. This is one of many examples of loss of market to U.S. industry. The Electronic Industries Association (EIA) is seeking ways to overcome this loss. The EIA, as a focal organization for U.S. electronics, should be contacted and solicited for their input to NASA activities in U.S. advanced communications component research and development.

2.7.5 Academic Community

The Committee suggests that the communications engineering departments of the academic community form a potential constituency that could significantly enhance satellite communications R&D. Key members of that community should be informed about the NASA program and given an opportunity to provide input.

This may conveniently be done through a summer study review of the NASA strategic plan in communications.

2.7.6 Department of Commerce

Starting in the 1970s other countries expanded their satellite technology capabilities and are now aggressively building and marketing products worldwide. These include satellite components, complete satellites, and launch services. Japan leads the world in Earth station production. Since satellite communications are thus far the only commercially viable application, these countries are spending a significant share of their space funds for such communications developments. To counter these efforts, the Department of Commerce should be kept advised of the need for continued R&D in this area, and its help should be sought in formulating R&D programs that would effectively help U.S. industries to meet foreign competition.

3.0 SATELLITE REMOTE-SENSING RESEARCH AND DEVELOPMENT

3.1 Introduction

One of the most rewarding elements of the national space program has been satellite remote sensing. Over the years an impressive series of increasingly sophisticated and varied satellites has made important contributions to the understanding of our planet and to applications with immediate and practical significance to mankind. We are now in the midst of a significant transition from isolated experimental and operational spacecraft toward a program based on much larger multipurpose platforms like those envisioned for the Space Station complex and those provided by the space shuttles. Furthermore, as the original scientific achievements lead increasingly to new operational requirements, the issues of balance between technology, basic science, practical applications research, and technology transfer assume increased importance and are the subject of debate.

For these reasons it is particularly appropriate at this time to review the rationale for the program and its various elements, and to understand their respective constituencies. This section provides such a review following a summary of the history and current status of the remote-sensing program.

3.2 Historical Overview

3.2.1 Historical Summary

Over the last quarter century, satellite remote sensing of the Earth has made great progress and provided important benefits to mankind. In the same speech that initiated the manned lunar landing (Apollo) program, President John

F. Kennedy also called for the establishment of an operational weather satellite system -- based upon NASA-developed technology (e.g., TIROS-1, launched in 1960), to be managed by what is now the National Oceanic and Atmospheric Administration (NOAA) (4). Later, in 1972, the United States initiated land remote sensing with the launch of Landsat-1, as part of a broadly based national effort in which NASA developed the technology in cooperation with the Departments of Commerce (through NOAA), Agriculture, and the Interior. NASA's satellite remote-sensing applications R&D reached a zenith in 1978 with NASA's launch of five satellites: Landsat-3, an improved version of land observing satellite; Seasat, the first oceanographic satellite; TIROS-N, the prototype of the current operational weather satellite series; Nimbus-7, the first satellite devoted to atmospheric chemistry and environmental quality; and the Stratospheric Aerosol and Gas Experiment (SAGE), an initial effort in NASA's Upper Atmosphere Research Program.

Remote-sensing techniques have been widely applied for weather prediction and tracking storm systems, agricultural assessment, forestry, hydrology, land-use assessment, mineral and petroleum exploration, range management, sea-state forecasting, ship routing, and in many other areas. In addition to these immediately practical applications, NASA decided in the late 1970s to include in its remote-sensing research program a more basic, long-range, scientific R&D effort, focused on Earth system science, as will be discussed later in greater detail.

Thus, for over a quarter of a century, NASA has defined, promoted, and implemented U.S. remote-sensing programs to establish a position of technological leadership that benefits all mankind. The operational weather satellite systems, the quasi-operational land satellite system, and the experimental ocean satellite system are acknowledged technological successes within their original program objectives. NOAA, the Department of Defense, and to a lesser extent other government agencies have all made major use of this new technology as well as of the collected operational and research data.

3.2.2 Current Status of Remote-Sensing Programs

Remote-sensing programs can be conveniently discussed by grouping them into four categories: observations of the atmosphere, land, and oceans, and those leading to simultaneous observations of all three in support of Earth system science.

NASA's atmospheric remote sensing programs have been oriented towards operational use by NOAA as weather satellites, or towards scientific advances relating to the study of Earth as a unified system involving the interactions among atmosphere, land, and oceans. The latter programs will be discussed separately under Earth system science. In the meteorological remote-sensing program NASA has been largely responsible for smoothly husbanding the development of advanced technology for weather satellites from basic science through applied research, technology demonstration, and the eventual transfer of the new capabilities to NOAA's operational systems. In this process the NASA/NOAA relationship was governed by an agreement on agency roles and responsibilities spelled out in a joint Memorandum of Understanding and approved at the White House level (5). Under this agreement NASA, as the space technology R&D agency, budgeted for and provided adequate funding for the Operational Satellites Improvement Program (OSIP). Recently, however, in response to the FY 1984 reductions, NASA has eliminated OSIP from its budget and thus signaled an end to the fiscal support for the fine NASA/NOAA cooperative arrangement, which contributed so much to the success of the meteorological remote-sensing program. Furthermore, since NOAA was unable to pick up this effort, the termination of OSIP left the operational weather satellites without an improvement program, thus accelerating their obsolescence.

The land remote-sensing program was declared operational in 1979, and the responsibility for the operation of Landsat was gradually transferred to NOAA in the Department of Commerce. In parallel with this transfer President Carter declared the commercialization of Landsat as a goal of his administration, and NOAA was directed to study whether land remote sensing could ultimately be operated by private industry. This process of commercializing the land remote-sensing program was then accelerated by the present administration and as this Report goes to press, the Department of Commerce has reached agreement with the Earth Observation Satellite (EOSAT) Company for operation of the Landsat system. EOSAT is to operate Landsats-4 and -5, develop and launch Landsat-6 and -7 (which are to use the same thematic mapper sensors as Landsat-4 and -5), and is committed to sustain the operation for 10 years. However, the financial basis of the arrangement contains no provisions for further system improvements or for R&D to extend the uses of the gathered data.

The continued improvement of the land remote systems is important not only because it brings with it additional scientific and commercially valuable capabilities, but because it enables U.S. industry to maintain an effective competitive edge in world markets. France has recently launched the Systeme Probatoire d'Observation de la Terre (SPOT) satellite to provide commercial sale of land remote sensing data in direct competition with EOSAT. Japan and the European Space Agency (ESA) also are expected to launch land remote-sensing systems by the end of this decade.

Recognizing the need for continuing improvements of the land remote-sensing systems, the recently enacted Title V of Public Law 98-365 (Landsat Commercialization Act) directs NASA (and the Departments of Commerce, the Interior, and Agriculture) to continue remote-sensing R&D programs. However, as of this time there is no clear indication how this support of privately operated satellites will be carried out. A modification of NASA priorities to increase the emphasis on R&D of commercially needed sensors and systems is clearly needed.

The ocean remote-sensing program is still in the early technology demonstration phase. Even though the Seasat spacecraft failed after 100 days in orbit, subsequent analyses of the data confirmed the value and utility of satellite remote sensing for large-scale oceanography, sea-state forecasting and monitoring, ship routing, and other applications. But since Seasat there have been no follow-on missions to verify and improve ocean remote-sensing techniques. The Navy recently launched a GEOSAT (altimeter) mission based on Seasat technology and initiated development of the Navy Remote Ocean Sensing System (N-ROSS) on which NASA will fly an advanced scatterometer (NSCAT) for improved ocean surface wind measurements. NASA is currently seeking authority to begin the TOPEX/Poseidon mission -- an advanced altimeter for the measurement of sea surface mean height, which in turn should permit determination of the direction and speed of ocean currents. N-ROSS and TOPEX/Poseidon are expected to be launched in the early 1990s, more than a decade after Seasat. Still, planning, analyses, and applications research are needed now to ensure effective real-time use of the N-ROSS and TOPEX/Poseidon data when they become available.

Great interest in Earth system science has been stimulated by (1) awareness of the complexity and vulnerability of the Earth's natural systems and (2) by the potential of remote sensing to provide long-term data over the complete globe and with successive measurements made within a relatively short time. The Office of Science and Technology Policy (OSTP), the National Academy of Sciences (NAS), and the International Council of Scientific Unions (ICSU) are all preparing reports on this subject. Within NASA, among the Earth science oriented missions two are currently under development (NSCAT and UARS [Upper Atmospheric Research Satellite]) and two additional ones have recently been proposed (TOPEX/Poseidon and Eos [Earth Observing System]). Furthermore, the Earth System Sciences Committee (ESSC) of the NASA Advisory Council (NAC) is planning an integrated and comprehensive program of research focused on Earth as a single system.

All the activity in this area implies that in the future Earth system science will likely dominate remote sensing, and this new emphasis, together with the need to support the R&D of the operational meteorological and land sensing satellites, suggests the reexamination of the rationale and constituencies of NASA's remote-sensing program, which follows below.

3.3 Rationale for NASA's Remote-Sensing Program

The rationale for NASA's remote-sensing program rests on three bases: the legislative mandate; the need for Federal Government involvement; and NASA's capability, resources, and experience to fulfill the government role.

3.3.1 Rationale for Federal Government Involvement in Remote-Sensing R&D

The Space Act, Clean Air Act, and Landsat Commercialization Act (Public Law 98-365) provide the legislative mandate for continued governmental involvement in remote-sensing programs. But the mandate is different for weather, land, ocean, and Earth system science satellites.

For weather satellite systems Title VII of Public Law 98-365 specifically forbids commercialization even if this would appear to be in the national interest. The rationale for government operation of these systems is based on its ability to provide almost every citizen with a broad range of benefits, some of which, because they involve protection of life and property from severe weather or the fulfillment of international commitments to exchange weather data, are clearly governmental responsibility. Weather satellite systems may thus be considered a form of public service, and governmental support of their R&D is clearly appropriate.

For land sensing systems, Public Law 98-365 mandates commercial operations. However, as already mentioned, Title V of that same law specifically directs NASA and the Departments of Commerce, the Interior, and Agriculture to continue R&D activities of these systems. An insight into the congressional rationale for this provision occurred at a 1985 hearing (6), when the members of Congress recognized that the newly created industry will be unable to fund the long-term, high-risk, high-cost R&D efforts in the face of foreign competition and remarked that "we should not repeat the mistake we made in communications." The need to overcome the foreign competition is in the national interest because the ability to sell some of the information gathered by remote land sensing and, possibly, some of the associated technology in world markets would improve our grossly unfavorable balance of trade. In addition, one should note that the information obtained by land remote sensing is likely to become increasingly important in international negotiations involving boundaries and cross-boundary pollutants. For this reason, it is again in the national interest to retain within the government expert, unbiased, technical support to help formulate and defend U.S. positions in such international negotiations.

The remote sensing of the oceans and Earth systems sensing are not specifically mentioned in Public Law 98-365, probably because their potential is still in the discovery state and therefore their commercial value, at present, cannot be fully assessed. It is possible that some of the information resulting from remote sensing of the oceans may eventually be sellable to shipping companies or fishermen. But it is already very clear that both these sensing modes can provide important scientific information, which ultimately may lead to broad societal benefits. Therefore the government support of their R&D is justifiable as a form of public service.

3.3.2 Rationale for NASA's Remote-Sensing R&D Programs

In 1963 Congressional appropriations and Executive branch interagency agreements designated NASA as the civilian space R&D agency, while mission agencies such as NOAA and the Department of Agriculture would manage operational satellites. In this way, in response to Section 102(c)(1) of the Space Act, the Federal Government avoided unnecessary duplication of space R&D capabilities in each of the mission agencies. As a result, NASA has over the last 20 years developed extensive R&D capabilities and resources. For instance, to supply advanced instruments for the weather satellites, NASA not only developed the hardware engineering capability but also developed extensive capability in atmospheric science, forecast modeling, and computers to run the models to ensure that the space and ground systems would meet specified requirements. The same can be said for (1) NASA's work with NOAA, the Environmental Protection Agency, and others in upper atmospheric research, where NASA scientists and NASA-sponsored researchers prepare biennial ozone assessments and figure prominently in the large international assessments prepared every few years by NASA, the World Meteorological Organization, and other U.S. and world agencies (7); (2) NASA's work with NOAA, the Departments of Agriculture and the Interior, and others in land remote sensing; and (3) NASA's work with the Navy, NOAA, and private industry in remote sensing of the oceans. Thus, NASA is unique among the Federal agencies in its capability to conduct remote-sensing R&D of the atmosphere, the land, and the oceans.

Given the clear need for Federal government involvement and NASA's extensive technical, managerial, and equipment resources, it is only reasonable that NASA continue to utilize those resources for the nation's benefit. A transfer of these capabilities to another agency or entity would result in great disruption and delay of needed R&D support.

Furthermore, NASA's remote sensing of the Earth and its environment is synergistic with NASA's remote sensing of the planets and deep space. For instance, the Advanced Digital SAR Processor (ADSP), which will be used to analyze synthetic aperture radar (SAR) data of the cloud-shrouded planet Venus, will also be used to analyze images of the Earth obtained by the Shuttle Imaging Radar-B (SIR-B). Similarly, the submillimeter detector being developed to analyze the spectra of interstellar grains will also be used to analyze the spectra of stratospheric constituents in Earth's atmosphere. Since NASA will require these R&D capabilities for its space science research, developing such capabilities in other agencies would lead to inevitable duplication.

3.4 The Remote-Sensing Constituency

3.4.1 Introduction

As part of the development process for new technologies and the services based upon them, it is essential to have two-way communication with the potential users of these technologies and services. It is also essential to begin early in the development process to structure and shape the resultant systems and services optimally to match user needs. Although there has generally been adequate communication in the area of weather sensing, the lack of adequate mechanisms for such communication in the case of land and ocean sensing has from the very beginning hampered the development of representative user groups. The problem has been particularly noticeable with respect to land-sensing applications, which is unfortunate because these applications have the greatest potential for the formation of a broadly based constituency. It is possible that this has occurred because the potential users of land-sensing data tend to be widely dispersed and have very different interests.

As might be expected, the present constituency of remote sensing reflects the perceived state of the benefits provided. Weather satellites, whose benefits affect almost every citizen, have a user group that forms a significant constituency. Earth system sensing satellites, whose benefits are as yet not so apparent, have essentially no constituency. For this reason it is convenient to discuss the remote-sensing constituencies separately for weather, land, ocean, and Earth system sensing.

3.4.2 Weather Sensing and Long-Range Forecasting

The two principal operational agencies that provide weather data are the Department of Defense and NOAA, both of which manage operational weather satellite systems that continue to draw upon technology advances previously made by NASA and its technological partners. However, as already pointed out, NASA's current R&D in this area is in limbo, and to resurrect it the immediate restoration of the previously effective cooperation between NASA and NOAA is essential. Additional constituencies with a need for R&D in weather sensing could conceivably be found within the Department of Defense and within the television industry, which make weather maps so important to its daily news coverage.

It should be noted that to develop new constituencies with interest in weather systems research, that research would have to be pointed at improving the accuracy of long-range forecasts. This probably means that future R&D should put greater emphasis on climatic studies and Earth system science than on improvements of weather sensing. Recognizing this, NASA has already developed a significant user group in the area of climatic studies, which complements similar activities in the academic community and elsewhere. Of course, should the accuracy and details of long-term weather forecasts improve enough to make them really meaningful and dependable, it is likely that additional users would be found among the countless people whose planning critically depends on weather, such as farmers or heating oil and gas distributors.

3.4.3 Land Sensing

Though the potential to provide important benefits to a multitude of industries and to address a broad range of critical problems by use of land remote sensing has been demonstrated by the Landsat satellites, the conversion of this potential into tangible benefits has, in general, not occurred. While there are many reasons for this, there is no doubt that time delay in availability of the data made it useless for many potential users, such as crop forecasters or fishermen. However, for oil and nonrenewable resource explorations, immediate availability of the sensed data is not important, and for these purposes remote sensing proved itself beneficial. In fact it is so beneficial that users with these interests formed the Geosat Committee Inc. to represent them more effectively. The Geosat Committee has been vocal in support of R&D for land sensing and forms a significant constituency. In addition, land sensing received some very limited support from the Department of Agriculture and the U.S. Geological Survey.

The advances in R&D that would make the benefits of land sensing meaningful to a wide community of users are not limited to improved spaceborne sensors. Almost all users depend heavily on ground data processing, which in turn, directly affects the time when the processed data becomes available. Near real-time processing, rapid distribution (possibly directly from the satellite) of newly collected data, and rapid access to desired segments of previously archived data are the kind of improvements that would satisfy the requirements of many new users. Although some of these improvements are operational, many others require refocusing NASA's future R&D efforts in the land-sensing area. If and when the data become available in a timely, dependable, and ready to use form, other groups of constituents will become approachable. These are likely to include such diverse groups as commodity traders; fishermen; and urban, land, and water resources planners. Disparate user groups can probably be best approached through their professional and trade organizations or aggregated into a consortium similar to the Public Service Satellite Consortium (PSSC), which effectively represents varied users of communication satellites.

3.4.4 Ocean and Earth System Sensing

At the present time the civilian ocean sensing and Earth system sensing programs serve primarily to acquire fundamental scientific and technical knowledge, which may greatly enlighten our understanding of the oceans and help in dealing with ever more pressing environmental problems. For this reason their immediate support (outside of the Navy) is likely to come from scientific and academic circles. In recent years these communities were principally involved as users and interpreters of data. In order to form a constituency it is recommended that NASA institute broader involvement of the academic community, not only in data analysis and interpretation but also in instrumentation and concept development. To do that, NASA should formulate a process to solicit instrument and measurement concepts from the academic community and competitively select a portion for proof-of-concept development. This would encourage the participation of professors and graduate students. NASA has initiated such an activity in its planetary and astrophysics programs with good results.

Eventually, ocean sensing may be expected to provide information that should improve our ability to develop and utilize ocean resources, such as fisheries, oil and gas, and deep sea minerals and should allow a more efficient use of our commercial and naval fleets. It is clear that to reap many of these benefits, the sensed information will have to be provided in real time and delivered in an appropriately processed form. Therefore, it is important that NASA start involving the representatives of these industries in the establishment of ocean data acquisition and processing requirements.

4.0 MICROGRAVITY RESEARCH AND DEVELOPMENT

4.1 Introduction

NASA's program in microgravity science and applications encompasses research, analysis, and flight programs in areas in which a microgravity environment can be exploited for advances in science, technology, and commerce. The current program addresses the subfields of metals and alloys, glasses and ceramics, biotechnology, electronic materials, combustion science, fluid dynamics and transport, and fundamental areas of chemistry and physics, for example, phenomena near critical points.

Those fields have been selected to exploit the unique features of low gravity with respect to phenomena such as natural convection, sedimentation, hydrostatic pressure effects, and containerless manipulation of fluids. These features have the potential for significant technological and commercial advances; furthermore, this potential is likely to be fulfilled provided that NASA reduces the risk to industrial participation by creating and sustaining a suitably fertile environment for microgravity research, development, and commercialization. Essential ingredients of such an environment are: (1) a well-organized and supported cadre of ground-based researchers, (2) frequent access to space for adequate periods of time, (3) development of the necessary flight hardware, (4) program continuity for assessment of results and liaison with other researchers in the international community, and (5) stimulation of industrial interest.

While the constituency for microgravity research remains to be developed, potentially it ranges from university scientists to industrial entrepreneurs.

A successful program will generate fundamental new knowledge, technological information of value in the improvement of terrestrial processes and products, and a foundation for space-based commercial operations. For example, the microgravity environment can now be used to grow protein crystals sufficiently large to enable structural analysis by X-ray diffraction (scientific knowledge). This should lead to the synthesis of new biologically-active substances (technological information) and ultimately to new drugs for the treatment of disease (commercial product). Other examples are products with a high intrinsic value per unit weight, such as novel electronic, optical, and magnetic materials. The advent of a permanently manned orbiting laboratory (Space Station) will vastly increase the duration and frequency of access to a low-gravity environment for the purposes of processing materials and biological specimens. It will also permit an interactive mode of research that should provide the opportunity for proof of concept and exploitation. It is essential that this program be nurtured during the intervening years to provide the necessary new hardware, the strong terrestrial research base, and the extensive flight experience aboard the Space Shuttle necessary to meet this window of opportunity and encourage commercial development.

4.2 Microgravity Research and Its Potential Impact

The current NASA program in microgravity science and applications is a well-balanced program of basic and applied research in areas where a knowledge of gravitational acceleration effects will contribute to our understanding of the complex processes involved in such diverse areas as preparing, purifying, and characterizing a broad spectrum of materials or of the combustion processes relevant to many energy conversion and processing technologies, as well as safety issues. The benefits may be indirect, in the sense that space experiments will be used to improve or enhance the control over ground-based processes, or direct, in which case they will lead to the processing of materials in space or improvement of the spacecraft environment.

Because there are important differences in the behavior of fluids in a low-gravity environment as compared to Earth, attention has been focused primarily on the role of fluid phases in the processing of materials and biological specimens. For example, natural convection that results from the combined influence of temperature and concentration gradients (called thermosolutile convection) has been found to influence crystal growth on Earth in very intricate ways that can be reduced or eliminated in a low-gravity environment. Such effects play an important role in the homogeneity and degree of perfection of crystals grown from the melt and may also play a role in determining the microstructure of concentrated alloy systems, a long-standing problem in materials science and technology.

The same reduction in buoyancy forces and the concomitant reduction in sedimentation create an ideal environment for the purification of human cells from which may be extracted important therapeutic agents such as urokinase, which is used to dissolve blood clots, erythropoietin, used in the treatment of anemia, and growth hormone, which regulates the growth of human cells. Such disease states as diabetes, pernicious anemia, and coronary thrombosis may be controlled eventually by pharmaceutical potentially available from bioprocessing in space.

The ability to reduce segregation due to buoyancy and sedimentation suggests the possibility of the formation of solids with variable density, resulting in new configurations for chemical processing as well as the production of new forms of composite materials.

The behavior of liquid floating zones, in which hydrostatic pressure plays an important role in determining zone size and shape, has been studied and modeled. In a low-gravity environment, floating zones of larger size can be stable, and improved floating zone techniques could lead to significantly improved crystals. However, since free surfaces with temperature or concentration gradients along them are inherent to floating zones and other crystal growth configurations, it will be necessary to understand better the role of associated thermocapillary flows before conclusions can be drawn concerning the potential of this process.

The possibility of containerless processing offers the novel capability of manipulation of ultra-pure liquids at high temperatures, thus permitting such techniques as the deep undercooling of molten drops below their normal crystallization temperatures; this can sometimes result in the formation of new structures, including amorphous solids. Containerless processing also allows the study of the thermophysical properties of molten reactive materials without contamination, an important area of interest at the National Bureau of Standards and at other laboratories concerned with the measurement of thermophysical properties at high temperatures.

Buoyancy-driven natural convection can have a profound effect on the intensity of combustion, either by augmentation or reduction, depending on the orientation of the combustible material relative to gravity. A microgravity environment provides the opportunity to test the effects of this important variable, and the results are likely to find use in the improvement of such equipment as automobile engines, jet engines, gas turbines, and kilns. Fire safety either on Earth or in a spacecraft environment, as evidenced by the Apollo tragedy, is a critical area in which such fundamental information is vital.

The often-asked question, "On which areas should NASA concentrate its efforts in microgravity research?" cannot at present be answered with certainty. Nevertheless, this Committee believes that the areas discussed above are exemplary insofar as the history of the field is concerned and show sufficient promise to be pursued. The unique characteristics of many microgravity techniques should lead to exciting new scientific discoveries over the next 5 years. This is because of the opportunity to conduct repetitive studies under the relatively long durations of low-gravity environment. Such studies are now available on Space Shuttle flights and, by the mid 1990s, are expected to become available aboard a manned Space Station.

The potential benefits of R&D in microgravity research are manifest. Unique technologies must be developed, such as containerless processing and special separation techniques that enable materials to be manipulated in space, which ranges from difficult to impossible at 1-g. Furthermore, attention must focus on materials with a value sufficiently high per unit volume that the cost of processing in space is not a major deterrent to the market. Pharmaceutical materials are an example of such products. However, the competitive and rapidly evolving technology of such materials makes it necessary to reduce the time required for the development and demonstration phases, so that space discoveries are not readily eclipsed by terrestrial progress.

In assessing potential benefits, it should be remembered that the time for new materials technology to evolve can be long: 15 years of development were required to produce viable, directionally solidified turbine blade materials, and 25 years were required for gallium arsenide to be used in high-speed circuits, long after its recognition as a high-mobility semiconductor by solid-state physicists. When the relative inaccessibility of space is added to the usual R&D constraints, the evolution time for commercialization may become even longer. Therefore, it is not appropriate to focus attention on quick commercial benefits from investment in space research. Attention must be paid to the long-term planning and scientific investments necessary to enable future technological capabilities to evolve.

It is important to recognize at the outset that microgravity research will yield two results. The first is fundamental scientific and technical knowledge that may be used to improve life and processes on Earth; the second, which derives from the first, is the development of products that may actually be manufactured in space. Both results are significant and either should be considered a successful outcome. To achieve them, the university as well as the industrial communities must be supported in the early phases of this research activity to establish which of the many low-gravity areas have the best economic viability.

This effort requires two components. First, there is a need for a continuing and expanding science and technology base that employs university laboratories for basic understanding and industrial laboratories for both basic understanding and applications research. The results of this research will be disseminated through scientific journals and trade papers, but an active commercialization effort directed at industrial/commercial entities must also be supported. The second component is continuing support of the national facilities necessary to enable experimental verification of the results from university or industrial research programs. NASA has already implemented such facilities as drop towers and tubes and specialized laboratory facilities. The agency has developed aircraft and flight techniques that provide much longer durations; however, the permanently orbiting Space Station will provide the best environment for the pursuit of this work. In addition, specialized equipment such as furnaces, levitation facilities, bioprocessing apparatus, and characterization facilities are essential and must be developed.

4.3 Implications of the Space Station

The Space Station, planned to be operational by the mid-1990s, will provide a near-continuous microgravity environment for exploitation by scientific, technological, and commercial constituencies. This presents a window of opportunity for proof-of-concept in such disciplines as materials processing, biotechnology, and combustion science; indeed, a microgravity science laboratory module has been included as a part of the initial operating configuration of the Space Station. For the first time, adequate time, reasonable power, and continuous manned interaction will be available to the community. Of utmost significance, the Space Station will provide the means to conduct interactive (with ground-based researchers through communications links) and adaptive (in orbit) experimentation, thus permitting a mode of research that has proven to be effective on Earth. This enhanced operational mode will significantly accelerate the discovery rate, will tend to reduce the operational costs, and should further encourage the involvement of leaders in the materials scientific community.

In order to make effective scientific, technological, and commercial use of a permanently orbiting space laboratory, it is helpful to remember some important lessons learned from previous space experiments in microgravity science and applications. A strong ground-based research program is essential both as a source of well-conceived space experiments and also as supporting research to provide the tools, thermophysical data, simulations, and numerical modeling that are essential to interpreting and understanding the significance of experimental results in space. In addition to the support of research and technology, a better appreciation of hardware design and development approaches has been gained from the limited spaceflight opportunities to date. An experiment-specific and modular approach to hardware is favored over large-scale general purpose equipment, although the inventory of developed space hardware has served the useful purpose of performing simple initial experiments on many occasions. Simple integration of this hardware into new space systems is enhanced by a modular approach using standard interfaces. Other important lessons relate to the flexibility of experiment protocols and operational modes.

The importance of fire safety aboard the Space Station cannot be overemphasized. Fire initiation and spread in a reduced-gravity environment must be understood in order to provide the required safety; this alone is sufficient reason to justify combustion research in microgravity, not to mention the additional benefits in the energy and engineering areas previously cited.

In addition, there are several important programmatic considerations that must be addressed in establishing inputs and requirements for the Space Station. It is essential that the program plan for the evolution of experiments and hardware be explicitly stated for microgravity science and applications. The plan should be a rational statement of the maturity, status, and schedule for the development and flight of experiments for program elements, both within existing budget constraints and without them. It is very clear that the current program size will neither satisfy current obligations to existing scientists nor develop future capabilities to be offered by the Space Station. An additional programmatic issue is the early resolution of conflicts over requirements from different disciplines using the various Space Station elements. For example, low gravity will be compromised by constant thruster firings required for high-precision pointing of astronomy or remote-sensing instruments. On the other hand, outgassing from materials-processing experiments poses the threat of contamination to the optics of such instruments. Concerned scientists and NASA planners should understand and resolve such conflicts as early as possible so that they can be reduced or avoided by good systems engineering and compatible design.

4.4 Rationale for NASA's R&D Role

The rationale for government's support of R&D in the space applications area lies in the tremendous potential inherent in microgravity research, a potential to make a transition to new technological and commercial endeavors of great value to the nation. The risks and costs involved in the development of such endeavors make it impossible to have them financed and undertaken by private sources, while the possible benefits to our society entirely justify government's active role. Among the various governmental agencies, NASA is the only logical choice for this role, because experience with the microgravity of space is almost entirely vested with that agency and its R&D communities. NASA operates the Space Shuttle, which currently provides the only opportunity to conduct long-duration experiments of this nature. This capability, as discussed above, will be greatly augmented with the advent of the NASA-manned Space Station.

4.5 Constituency Development

Since the applications of microgravity processing are still very much in the discovery stage, support for the program is most likely to come from those groups whose interests lie in this research area. However, once the practical benefits of microgravity processing have become clearer, additional industrial support may also be expected. Listed below are some of these groups, together with suggestions on how to encourage their formation and stimulate their commitment to this program.

4.5.1 Scientific and Technological Community

In this community, the development of an R&D constituency in microgravity science and applications can occur most naturally by a phased involvement in the understanding and use of low-gravity facilities. In the past, this involvement has stressed experiments ranging from simulation and modeling through the use of short-term facilities (drop towers, drop tubes, parabolic trajectories by aircraft and sounding rockets), longer term facilities (Shuttle and Spacelab), and finally, a permanent presence on an orbiting Space Station. Through the increasingly long time capabilities, full use of adequate scaling principles is essential to translate experience on shorter term, less expensive facilities to longer term, more expensive facilities in a cost-effective and scientifically justifiable manner. Although such a scenario should not preclude entrance of sophisticated experiments into longer term facilities without precursor or prototype demonstrations, the same evaluation criteria should be applied for selection.

The scientific and technological communities are sensitive to both the quality of work performed in the microgravity science program and to its relevance for other areas of science and technology. This concern arises because of the large amount of money required to carry out space experiments. Therefore, the merits of work performed in this program will be judged by the community of peers (1) through technical presentations by principal investigators at various technical society meetings and (2) through publication of papers in refereed scientific journals. Maintenance of high scientific standards is an essential prerequisite to involving scientists of high caliber in the program. Sustained commitment among such scientists then becomes a natural process, limited only by the availability of adequate funding and by access to a low-gravity environment on both a short-term and long-term basis.

4.5.2 Industrial Interest

There is some early commercial interest in materials processing in space, but it is premature for most industries to assess the commercial value of a low-gravity environment. In order to stimulate further industrial commitment, certain issues must be addressed: the time required to implement space experiments should be made as short as possible; the frequency of access to space and amount of experimental time should be optimized; costs for experiments should be reduced wherever possible; and an adequate knowledge base should be developed from which industry can better evaluate development risks. There is, in fact, widespread industrial interest in the NASA scientific programs in materials processing, as evidenced by a significant increase in Technical Exchange Agreements, some Joint Endeavor Agreements, and participation of industrial scientists in various science working groups and advisory committees.

The most important measure of industrial commitment and market-risk readiness is the amount of private investment that can be obtained for space-related activities; for example, private-sector funds in the emerging NASA Centers for Commercial Development of Space. The no-exchange-of-funds agreements currently used are also appropriate to encourage private industrial interest. However, as the limitations and impacts of these agreements become better understood, they should where necessary be continuously evaluated and revised into a workable framework for dealing with future commercial use of materials R&D and technology in space.

With regard to the development of an industrial constituency for space-related R&D, there are attractive opportunities for exploitation of high-technology processes. For example, in space protein crystals may be grown sufficiently large to allow the determination of their molecular structure by X-ray diffraction. Inasmuch as proteins are essential components of living matter, this type of scientific knowledge may well lead to the synthesis of novel pharmaceutical for selective attack on certain viruses and bacteria. Should these syntheses produce useful products, support may be sought from the pharmaceutical industry. There is also the possibility of commercial manufacturing processes in space, cases in point being the use of containerless melting for the preparation of high-purity optical fibers for the telecommunications industry, as well as novel semiconductors for the electronics industry. Correspondingly, the efficient separation of proteins and tissue cells by electrophoresis in space has the potential for becoming of long-range importance to the drug industry.

4.5.3 Federal Agencies

In microgravity science, there is little conflict with other Federal agencies. Coordination with the National Science Foundation, the National Institutes of Health, and the Department of Energy programs in materials, bioprocessing, combustion, and other research remains important in order to promote synergism. Recently, Department of Defense interest in the program has materialized. Several important activities at the National Bureau of Standards in microgravity research have been funded by NASA. The above examples show a confluence of interest; NASA should take advantage of this by leading the development of a coordinated support of activities.

4.5.4 International Interest

International interest in the microgravity environment ranges from the desire to have a tangible presence in space via the development of space hardware to scientific and even commercial results. The primary foreign effort, but the one that we know the least about, is that of the U.S.S.R. There is significant involvement of the European community, coordinated through ESA and in cooperation with NASA. International cooperation is, however, hampered by each nation's loyalties to its own industries and the difficulties of assuring uninterrupted funding commitments. An extensive discussion may be found in a recent report of the Office of Technology Assessment (8). The United States, France, and Germany lead the way in developing the ground-based science needed to exploit the microgravity environment; other countries, such as Japan, can capitalize on this basic science later and at less expense, if they wish. This mode of operation is consistent with the traditional leadership role of the United States in many areas of advanced technology. More rapid international exchanges of knowledge should be supported.

REFERENCES

1. See "Changes, Additions and Errata to October 1983 Edition of the Space Act" (October 1984).

2. Communications Satellite Act, 1962; this act implies that NASA must undertake R&D to become sufficiently knowledgeable in the area of communications so that its advice and cooperative and consulting efforts as called for by the Act are significantly meaningful.

3. NASA Authorization Act, 1984; Section 102(c)(5) states that the work should include the ground segment of the system, as well as development of technology for a first-generation, mobile communication satellite service jointly with industry and Canada.

4. President Kennedy's State of the Union Address to Congress Regarding the Space Program, May 25, 1961.

5. Basic Agreement Between the U.S. Department of Commerce and the National Aeronautics and Space Administration Concerning Operational Environmental Satellite Systems of the Department of Commerce, July 2, 1973 (first signed in 1964).

6. Joint Hearings of the Subcommittees on Energy and Environment and Space Science and Technology to the House Committee on Science and Technology, June 13, 1985.

7. Atmospheric Ozone 1985: Assessment of Our Understanding of the Processes Controlling Its Present Distribution and Change. World Meteorological Organization: Global Ozone Research and Monitoring Project, Report No. 16.

8. "International Cooperation and Competition in Civilian Space Activities - Summary," a report to the House Committee on Science and Technology and to the Joint Economic Committee. Office of Technology Assessment, July 1984.

APPENDIX: LEGISLATION

Following are sections from legislation cited in the report.

NATIONAL AERONAUTICS AND SPACE ACT OF 1958, AS AMENDED
DECLARATION OF POLICY AND PURPOSE

SEC. 102. (c) The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives:

(1) The expansion of human knowledge of phenomena in the atmosphere and space;

(2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;

(3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space;

(4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;

(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;

...

CHANGES, ADDITIONS AND ERRATA TO OCTOBER 1983 EDITION OF THE SPACE ACT

CHANGES to the Space Act

The FY 1985 NASA Authorization Act amended the Space Act in the following ways:

1. Sec. 110(a) of P.L. 98-361 amended section 102 of the Space Act in the following ways:

(3) by inserting after subsection (b) the following new subsection:

"(c) The Congress declares that the general welfare of the United States requires that the National Aeronautics and Space Administration (as established by Title II of this Act) seek and encourage to the maximum extent possible, the fullest commercial use of space."

COMMUNICATIONS SATELLITE ACT OF 1962
IMPLEMENTATION OF POLICY

SEC. 201. In order to achieve the objectives and to carry out the purposes of this Act....

(b) the National Aeronautics and Space Administration shall--

(1) advise the Commission on technical characteristics of the communications satellite system;

(2) cooperate with the corporation in research and development to the extent deemed appropriate by the Administration in the public interest;

(3) assist the corporation in the conduct of its research and development program by furnishing to the corporation, when requested, on a reimbursable basis, such satellite launching and associated services as the Administration deems necessary for the most expeditious and economical development of the communications satellite system;

(4) consult with the corporation with respect to the technical characteristics of the communications satellite system;

...

LAND REMOTE-SENSING COMMERCIALIZATION ACT OF 1984
CONTINUED FEDERAL RESEARCH AND DEVELOPMENT

SEC. 501.(a)(1) The Administrator of the National Aeronautics and Space Administration is directed to continue and to enhance such Administration's programs of remote-sensing research and development.

(2) The Administrator is authorized and encouraged to--

(A) conduct experimental space remote-sensing programs (including applications demonstration programs and basic research at universities);

(B) develop remote-sensing technologies and techniques, including those needed for monitoring the Earth and its environment; and

(C) conduct such research and development in cooperation with other Federal agencies and with public and private research entities (including private industry, universities, State and local governments, foreign governments, and international organizations) and to enter into arrangements (including joint ventures) which foster such cooperation.